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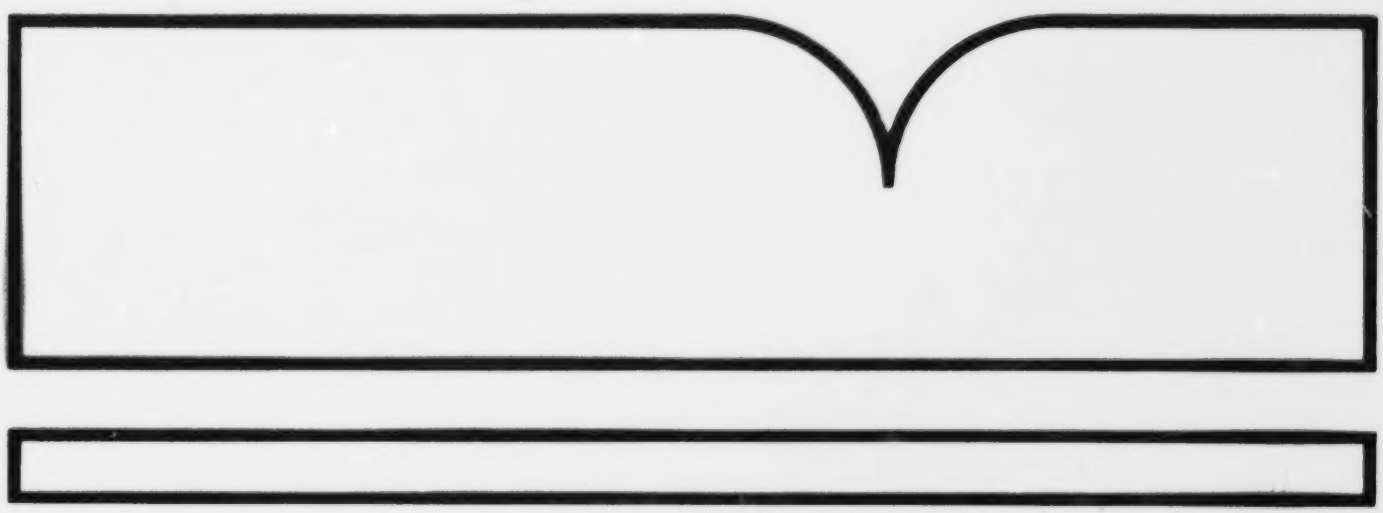
Municipal Waste Water as a Source of Cooling Water for California Electric Power Plants

California Energy Commission
Sacramento

May 80



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Tom MacDonald.

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This report discusses sources of municipal waste water for potential use as cooling water in California power plants. It notes the major factors which affect this practice. Municipal treatment facilities in California with discharge volumes deemed adequate to supply new power plants are identified. Also included is a summary of the experiences of several utilities in California and other western states with existing or planned applications of municipal waste water in power plant cooling towers.

KEYWORDS: *Electric power plants, *Cooling water, *Waste water reuse.

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MUNICIPAL WASTE WATER AS A SOURCE OF COOLING WATER FOR CALIFORNIA ELECTRIC POWER PLANTS

Prepared By
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Assessments Division
California Energy Commission

MAY 1980

ABSTRACT

This report presents the results of an investigation of sources of municipal waste water for potential use as cooling water in California power plants. It also presents the major factors which affect this practice. Municipal treatment facilities in California with discharge volumes deemed adequate to supply new power plants are identified. Also included is a summary of the experiences of several utilities in California and other western states with existing or planned applications of municipal waste water in power plant cooling towers.

Due to limited supplies of high-quality water, municipal waste water is increasingly viewed as an alternative source of supply for a variety of water uses, including electric power plant evaporative cooling. In California, enough municipal effluent is discharged to the ocean to conceivably supply the total projected cooling water needs of new power plants for the next twenty years or more. A number of existing applications of such waste water for power plant cooling, including several California cases, demonstrate the technical feasibility of its use for this purpose.

However, a combination of economic, environmental and geographic factors reduce the likelihood of widespread use of this alternative for meeting anticipated large increases in power plant water requirements in the state. The most important factors are:

- Long distances between waste water sources and appropriate siting areas for new power plants, necessitating costly and energy-intensive conveyance pipelines.

- Unresolved public health concerns with respect to aerosol emissions from cooling towers using waste water.

- Added costs and environmental effects of special treatment necessary to allow use of waste water for cooling.

- Reliability of waste water supply quality; usually, another standby water supply source will be necessary.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
I. WASTE WATER PRODUCTION AND POTENTIAL FOR RECLAMATION	2
II. EXTENT OF OPPORTUNITIES FOR POWER PLANT SUPPLY	17
III. FACTORS WHICH AFFECT FEASIBILITY OF USING WASTE WATER FOR COOLING	20
Waste Water Quality Characteristics	20
Extent of Municipal Waste Water Treatment	23
Cost of Effluent Purchase	25
Additional Treatment Necessary for Power Plant Use	25
Special Cooling System Design and Operating Modes	27
Conveyance Costs	29
Waste Water Supply Reliability	31
Environmental Implications	33
IV. APPLICATIONS BY ELECTRIC UTILITIES	42
Southwestern Public Service Company	42
City of Burbank	45
Nevada Power Company	46
Pacific Gas and Electric Company	48
City of Glendale	49
Palo Verde Nuclear Project	50
REFERENCES	52

LIST OF TABLES AND FIGURES

Page

Table 1. Municipal Waste Water Treatment Facilities Discharging 5,000 or More Acre-Feet Per Year 10

Table 2. Pathogenic Microorganisms Potentially Present in Sewage Effluent 41

Table 3. Applications of Municipal Waste Water for Power Plant Cooling 43

Table 4. Typical Water Analyses of Nichols Station of Southwestern Public Service Company 45

Table 5. Typical Water Analyses - City of Burbank Power Plants 47

Figures 1-5. Maps showing Locations of Municipal Waste Water Treatment Facilities Discharging 5,000 or More Acre-Feet Per Year

1. San Diego Region 5
2. Los Angeles Region 6
3. Santa Barbara Region 7
4. Monterey Bay Region 8
5. San Francisco Bay Region 9

INTRODUCTION

Municipal waste water effluent is increasingly regarded as a valued resource. In California, as well as in other western states, growing competition for available water supplies has fostered the realization that maximum water reuse should be considered wherever possible. At the same time, more restrictive effluent standards mandated by the Federal Water Pollution Control Act, and improved treatment facilities funded under the Act, have substantially upgraded the general quality of municipal effluent. As a result, reclamation of municipal waste water for further beneficial use has become an established practice in water-short areas.

In California and elsewhere, the major uses of reclaimed waste water have traditionally been irrigation of nonfood crops and landscape watering. Less common uses are recharge of groundwater basins, maintenance of recreational and ornamental lakes and industrial cooling. To date, a relatively small amount--about 7 percent--of the municipal waste water produced annually in the state has been reclaimed for direct reuse.(1) The drought experience of 1976-77 has heightened the emphasis statewide on increased effluent reuse. A State Office for Water Recycling has been created (within the State Water Resources Control Board), with a goal of tripling waste water reuse by 1980.

The State Water Resources Control Board's "Water Quality Control Policy on the Use and Disposal of Inland Waters Used for Power Plant Cooling" (June, 1975) gives priority to waste water that is discharged to the ocean as the best potential source of cooling water. The following sections present locations and quantities of such discharges and discuss factors which affect potential applications of this waste water for power plant cooling. An assessment of the technical feasibility of cooling system operation using municipal waste water is included, with discussion of example cases.

I. WASTE WATER PRODUCTION AND POTENTIAL FOR RECLAMATION

California municipalities annually produce about 3.1 million acre-feet (af) of treated waste water effluent.(1) About 200,000 acre-feet per year (afy) is directly reclaimed and reused. Another 800,000 afy is discharged to inland surface water or groundwater. This effluent, upon being recombined with the natural supply, is available for further in-stream or out-of-stream uses. Indirect reclamation of waste water discharged to inland waters has, therefore, become an established concept and is reflected in water accounting balances. In fact, waste water return flows may at times represent a significant portion of some stream flows. Although direct reclamation may be advantageous for receiving water quality, most of the effluent being discharged to inland waters does not represent a new source of supply. Nevertheless, inland waste water treatment plant effluents could, in some cases, represent more readily available (and more politically acceptable) sources of power plant cooling water than fresh water sources.

The remaining two-thirds—about two million afy—of the municipal waste water produced is discharged to the ocean (including its bays and estuaries) and thus can be considered as having "new supply" potential for reclamation. Emphasis is being placed on this waste water by the state's water agencies in their reclamation planning. This report also focuses primarily on waste water discharged to the ocean, since its use in lieu of inland water for power plant cooling would clearly represent a benefit to state water supply.

Many of the individual waste water treatment plants contributing to the total two million afy of ocean discharges are small, with effluent volumes incapable of serving the cooling needs of any planned generating facilities. As discussed in more detail in a subsequent section, the use of municipal waste water

in an evaporative cooling system will generally require operation at lower cycles of concentration and therefore require a somewhat larger make-up water volume compared with the use of a higher quality water source. Even though more intensive pretreatment and/or sidestream treatment can be performed to partially compensate for low initial water quality, an excess of supply make-up water should be planned for when municipal waste water is used. This will provide a margin of assurance for maintaining acceptable circulating water quality and minimizing cooling system operational problems.

Variability of effluent flows provides another reason for conservatively predicting amounts of municipal waste water required for power plant cooling. Generally, annual waste water treatment plant production of 1.5 times the annual power plant requirements should be available to provide a continuously adequate flow of make-up water without substantial storage.

Table 1 (page ____) lists all municipal waste water treatment facilities in California which discharge 5,000 afy or more of effluent to the ocean. Information on these facilities was obtained from a 1973 Department of Water Resources Study and updated for this report.(2) The 5,000 afy figure was selected arbitrarily and represents a sufficient volume to provide the annual evaporative cooling needs of 200-300 megawatts (MW) of steam-electric generating capacity. This volume could also serve the cooling needs of 600 MW of combined cycle capacity.

The list includes 25 facilities with discharges of 5,000 to 10,000 afy, twelve facilities discharging 10,000 to 20,000 afy, and twelve facilities with discharges of more than 20,000 afy. Five facilities in the latter category discharge in excess of 100,000 afy. Cumulatively, these waste water treatment plants produce about 1.8 million afy—or 90 percent of the total volume of waste

water discharged to the ocean. Only about 50,000 afy of waste water from these facilities was reported as currently being reclaimed, although this amount no doubt continues to increase significantly. Figures 1-5 show the locations of the waste water discharges listed in Table 1, most of which are in close proximity to the coast.

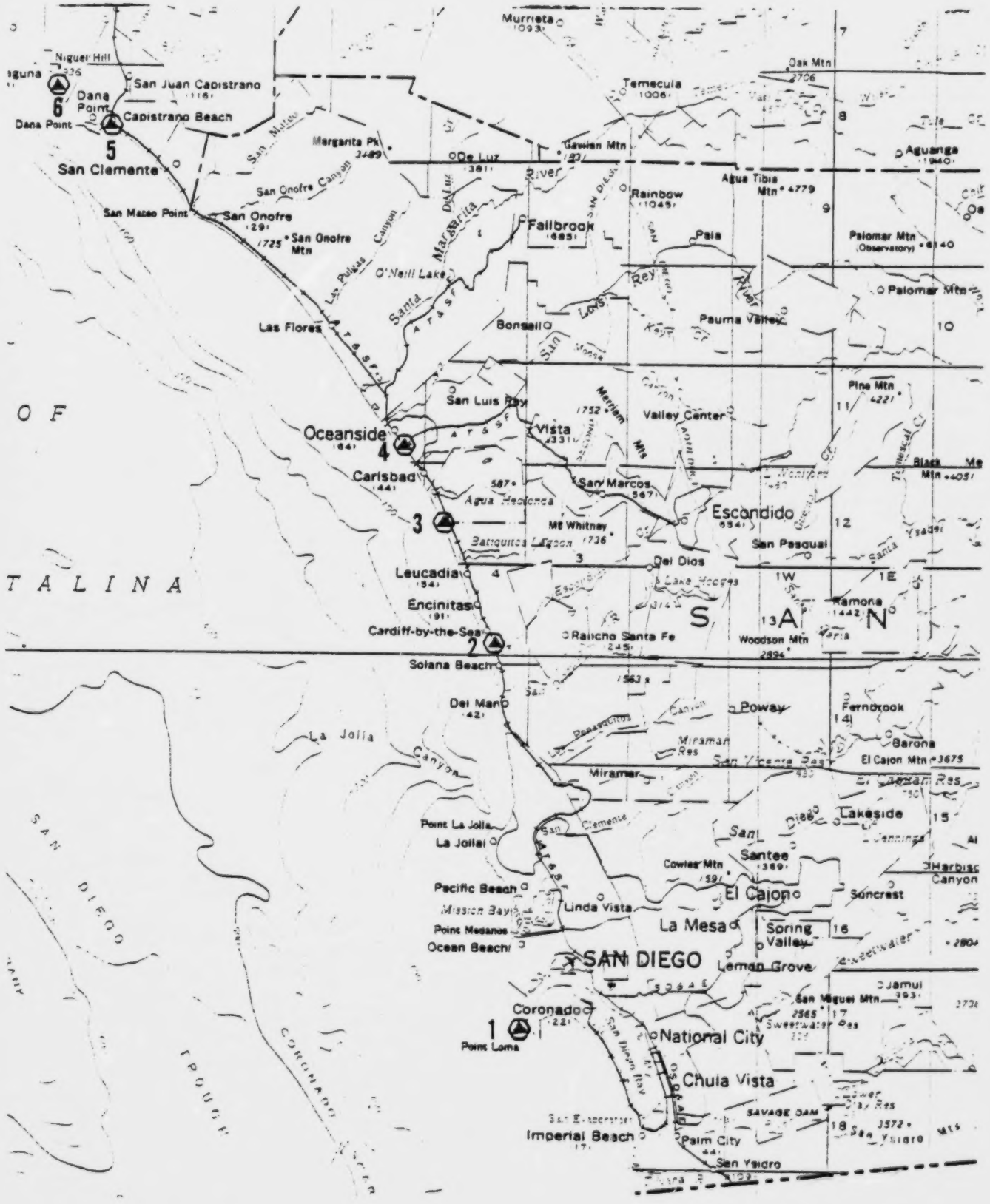

Figure 1: San Diego Region

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Municipal Waste Water Treatment Facilities Discharging 5,000 or more Acre-Feet per Year. (Numbers correspond to listing in Table 1).

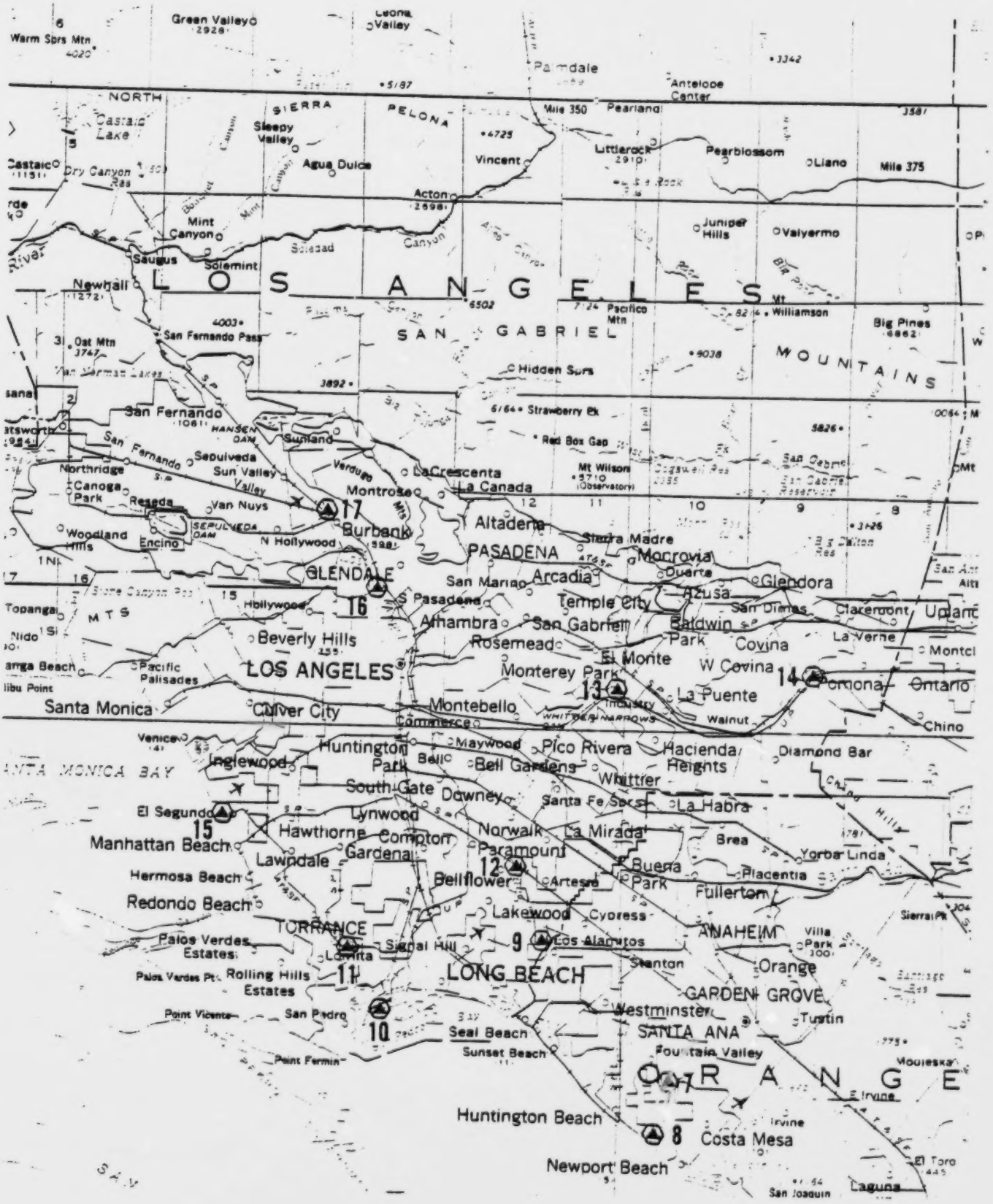

Figure 2: Los Angeles Region

Municipal Waste Water treatment Facilities Discharging 5,000 or more Acre-Feet per Year. (Numbers correspond to listing in Table 1).

Figure 3: Santa Barbara Region

Municipal Waste Water Treatment Facilities Discharging 5,000 or more Acre-Feet per Year. (Numbers correspond to listing in Table 1).

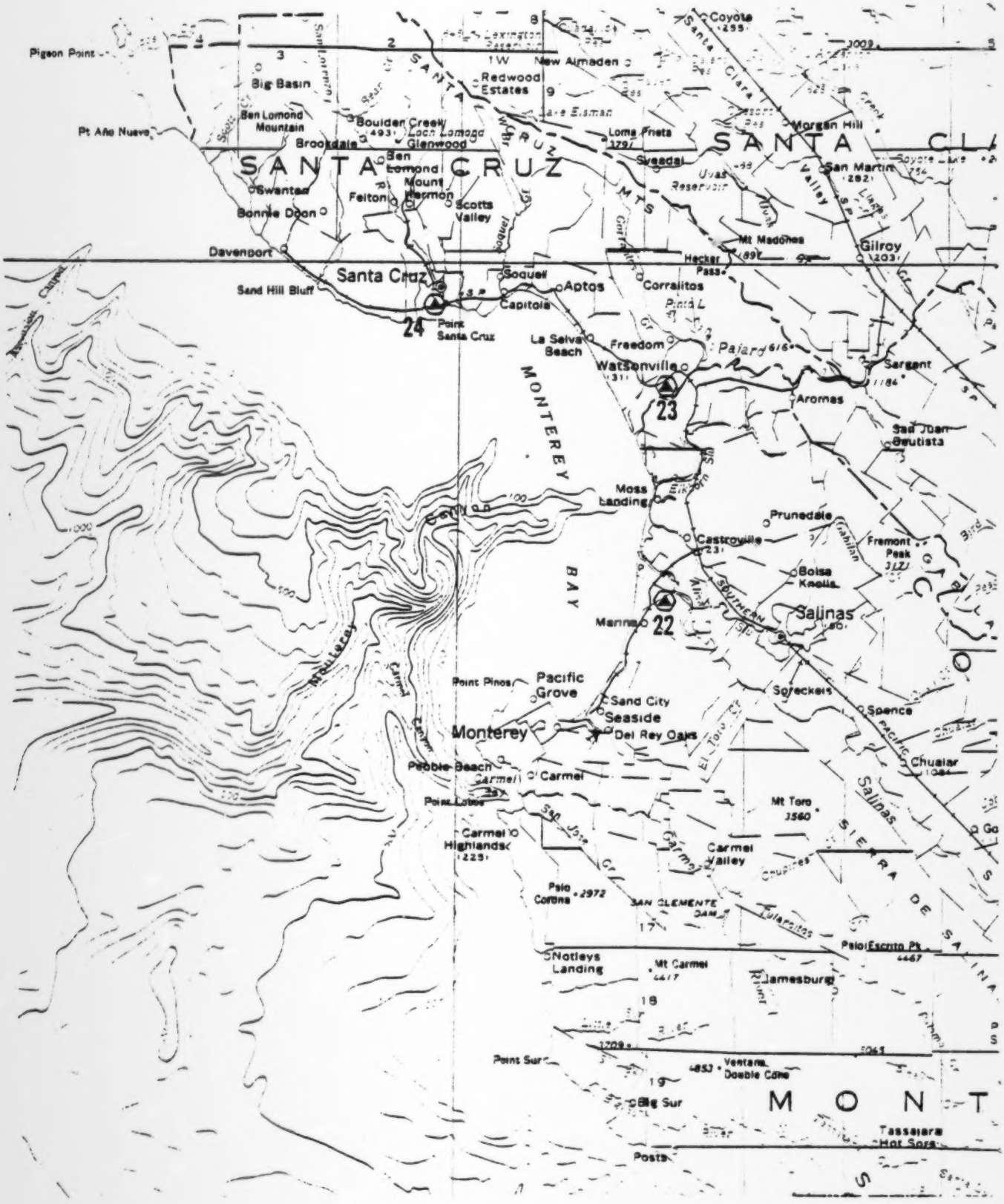

Figure 4: Monterey Bay Region

Municipal Waste Water Treatment Facilities Discharging 5,000 or more Acre-Feet per Year. (Numbers correspond to listing in Table 1).

Reproduced from best available copy.

Figure 5: San Francisco Bay Region

Municipal Waste Water Treatment Facilities Discharging 5,000 or more Acre-Feet per year. (Numbers correspond to listing in Table 1).

TABLE 1

MUNICIPAL WASTE WATER TREATMENT FACILITIES
DISCHARGING 5000 ACRE-FEET PER YEAR OR MORE
(See location maps, Figures 1-5)

No. on Map	Footnote No.	Facility	Treatment	Present Reclamation	Approximate N Discharge (AF
San Diego Region					
1	a	City of San Diego, Pt. Loma Plt.	Primary	none	140,000
2	b	San Diego Co. San Elijo Plt.	Combined Primary & Secondary	none	11,000
3		Encina Joint Sewerage Agency	Primary	none	12,000
4		City of Oceanside	Secondary	crop irrig. & g.w. recharge	6,000
5	c	S.E. Regional Recl. Authority	Secondary	irrig.	5,000
6	d	Aliso Water Mgmt. Agency	Secondary	none	5,000
Los Angeles Region					
7	e	Orange Co. San. Dist. Plt. 1	Secondary	landscape irrig. & g.w. injection	33,000
8	e	Orange Co. San. Dist. Plt. 2	Primary	landscape irrig.	150,000
9		L.A. Co. San. Dist. Long Beach Plt.	Secondary	none	5,000
10		City of L.A. Terminal Is. Plt.	Secondary	none	12,000

TABLE 1 (continued)

No. on Map	Footnote No.	Facility	Treatment	Present Reclamation	Approximate Net Discharg
11		L.A. Co. San. Dist. Joint Plt.	Primary	none	380,000
12	f	L.A. Co. San. Dist. San Jose Cr. Plt.	Secondary	g.w. recharge	12,000
13	f	L.A. Co. San. Dist. Los Coyotes Plt.	Secondary	none	9,000
14	f	L.A. Co. San. Dist. Pomona	Secondary	irrig.	7,000
15		City of L.A. Hyperion Plt.	Primary	none	390,000
16	g	L.A. Glendale	Secondary	irrig. & cooling	8,000
17	g	City of Burbank	Secondary	cooling	6,000
Santa Barbara Region					
18		City of Oxnard	Primary	none	15,000
19		San Buenaventura	Secondary	irrig.	7,000
20		City of Santa Barbara	Secondary	irrig.	12,000
21		Goleta San. District	Primary	irrig.	5,000
Monterey Bay Region					
22		Monterey Reg. San. Dist.	Primary	none	25,000
23		City of Watsonville	Primary	none	6,000
24		City of Santa Cruz	Primary	none	7,000

TABLE 1 (continued)

No. on Map	Footnote No.	Facility	Treatment	Present Reclamation	Approximate Net Discharg
San Francisco Bay Region					
25		City of San Jose	Secondary	none	100,000
26		City of Sunnyvale	Secondary	none	18,000
27		City of Palo Alto	Secondary	none	39,000
28	i	Menlo Park San. Dist.	Primary	none	6,000
29		City of Redwood City	Secondary	none	9,000
30		Cities of San Carlos-Belmont	Secondary	none	6,000
31	j	City of San Mateo	Primary	none	12,000
32		City of Burlingame	Secondary	none	5,000
33		So. San Francisco-San Bruno	Secondary	none	10,000
34		City & Co. of S.F., S.E. Plt.	Primary	none	25,000
35		City & Co. of S.F., Richmond, Sunset Plt.	Primary	none	24,000
36		City & Co. of S.F., N. Pt. Plt.	Primary	none	70,000
37		Marin Co. San. Dist.	Secondary	none	5,000
38	k	Napa San. District	Secondary	none	6,000
39	l	Fairfield-Suisun San. District	Tertiary	none	7,000

TABLE 1 (continued)

No. on Map	Footnote No.	Facility	Treatment	Present Reclamation	Approximate Net Discharg
40		Vallejo San. District	Secondary	none	8,000
41	m	Central Contra Costa San. Dist.	Secondary	cooling	20,000
42		San Pablo San. Dist.	Secondary	none	6,000
43		Richmond Mun. San. Dist.	Secondary	none	6,000
44		East Bay MUD	Secondary	none	100,000
45	n	City of San Leandro	Secondary	none	8,000
46		Oro Loma San. Dist.	Secondary	none	15,000
47		City of Hayward	Secondary	none	13,000
48		Union San. Dist. Plt. 1	Secondary	none	7,000
49		Union San. Dist. Plt. 2	Secondary	none	7,000

FOOTNOTES TO TABLE 1

a. City of San Diego - has developed plans for new secondary treatment facilities at existing Point Loma site and at new sites (including a site in the South Bay area). However,. may be a candidate for a secondary treatment waiver.

b. San Elijo - includes 2,300 afy of San Elijo primary effluent and 8,500 afy of Escondido secondary effluent.

c. SERRA - Plans to add waste water from San Clemente (about 1,000 afy).

d. AWMA - Plans to add additional regional effluent. Present contribution from the City of Laguna Beach has only primary treatment.

e. Orange Co. 1 and 2 - Combined effluents discharged to the ocean via single outfall.

f. L.A. Co., San Jose Creek, Los Coyotes and Pomona Plants - Discharge to concrete-lined channels various distances from the ocean.

g. City of Glendale and City of Burbank - Effluent not used for power plant cooling discharged to L.A. River system (concrete-lined channels).

h. Monterey Regional County Sanitation District - Addition of secondary treatment facilities planned for 1982.

i. Menlo Park Sanitation District - Effluent will be sent to Redwood City and Cities of San Carlos - Belmont plants by 1980.

j. City of San Mateo - Joint secondary facility with Foster City planned for 1980.

k. Napa Sanitation District - Discharge to Napa Slough.

l. Fairfield-Suisun Sanitation District - Discharge to Suisun Slough.

m. Central Contra Costa Sanitary District - Engaged in reclamation project with Contra Costa Water District.

n. City of San Leandro - Scheduled to receive additional waste water from several inland communities in near future.

The remaining waste water discharged to the ocean is dispersed among approximately 100 different treatment plants. Some of these may offer additional potential for providing cooling water for small power plants. A further possibility would be combining waste water effluents from multiple treatment facilities to provide the necessary volume for a single power plant.

A Department of Water Resources (DWR) report considered cases where municipal waste water facilities within individual counties would, in combination, supply 20,000 afy or more of effluent.(3) Fourteen combinations of municipal treatment plants within five mile radii were identified which cumulatively produce 20,000 afy or more. Eight of the combinations involve waste water discharged to the ocean; each of these includes at least one treatment plant listed in Table 1 and Figure 1-5.

Municipal waste water from inland communities generally does not offer a net water supply benefit as a reclaimed water source, but, in certain cases, may still represent an attractive cooling water supply. Waste water in excess of 5,000 afy is discharged by treatment plants in each of the following communities: Bakersfield, Chino, Concord, Fresno, Modesto, Redding, Riverside, Sacramento, Salinas, San Bernardino, Santa Rosa, Stockton and Thousand Oaks. The DWR report identifies six combinations of inland treatment plant within five mile radii which cumulatively produce 20,000 afy or more of effluent. They are located in the municipal areas underlined.

Projections of future municipal waste water production show increases from the present 3.1 million afy of effluent produced in the state to 4.1 million afy and 4.7 million afy by 1990 and 2000, respectively.(1) Certain basins are expected to increase waste water production at much faster rates than suggested by the statewide figures. Of the coastal basins with major reclamation potential, both

Basin 3 (Central Coast) and Basin 9 (San Diego) are projected to experience increases in waste water production of over 90 percent by the year 2000.(1)

At the same time waste water volumes are increasing, more emphasis on reclamation will likely result in a greater portion of effluent being reused. Power plant projects generally have more lengthy development periods than other types of projects (e.g. landscape, irrigation) that are candidates for waste water reuse. Therefore, effluent reuse by shorter lead-time reclamation projects could result in decreases in the volumes of effluent available for power plants despite the projected increases in waste water production.

The recent drought experience has demonstrated the effect of water conservation on domestic waste water production. Sewage flows in many communities were down about 20 percent from normal, with certain communities which practiced extensive conservation experiencing reductions approaching 50 percent. Continuation of conservation measures, while offsetting the increasing urban demand for fresh water, could also cause volumes of waste water available for reclamation to fall short of projections.

II. EXTENT OF OPPORTUNITIES FOR POWER PLANT SUPPLY

The figures in Section I for waste water production suggest that municipal effluent could provide several times the total amount of cooling water needed by future California power plants.* However, as illustrated in Figures 1-5, most municipal waste water effluents with the potential for advantageous use for power plant cooling are discharged to the ocean by coastal communities. The primary attractiveness of coastal power plant siting is, of course, the presumed availability of ocean water for once-through cooling. Therefore, the question arises as to what incentive exists to use cooling towers with municipal waste water at coastal sites. While it is true that once-through ocean cooling would be the preferred method at sites proximate to the coast,** regulatory problems may seriously constrain its further application. The use of cooling towers, despite their higher cost and efficiency penalty, could become necessary even at coastal or near-coastal sites, with municipal waste water representing an attractive source of make-up water.

A major factor which clouds the potential for ocean once-through cooling is whether siting additional power plants in the coastal zone is in conformance with the California Coastal Commission's restrictive land use designations. The set-back siting study addresses the potential for avoiding designated (protected) stretches of coastline by locating plants some distance inland, but close enough to use ocean water in a once-through mode. While a promising mitigation measure from land use and aesthetics standpoints, this concept is limited in its application potential by coastal topography, which would result

*California Energy Commission projections of cooling tower make-up water requirements for California power plants by the year 2000 range from 300,000 to 740,000 afy for a variety of electric generation scenarios.

**See _____.

in severe pumping energy penalties for most set-back sites. Also, this option would not mitigate the thermal discharge problem and, in fact, could increase mortality of entrained marine life.

The second looming uncertainty for once-through cooling with ocean water is the upcoming reissuance of thermal discharge guidelines under the Federal Water Pollution Control Act. The original guidelines were issued by the Environmental Protection Agency in October, 1974, and would have effectively mandated cooling towers in place of once-through cooling for most new power plants as well as many existing ones.(4) As the result of litigation by the electric utility industry, these guidelines were set aside and remanded to EPA for further consideration of their environmental impact, particularly with respect to water consumption in arid regions.(5) There is as yet no official indication of what direction the reformulated guidelines, expected in 1979, will take. However, the guidelines may again attempt to severely limit new once-through thermal discharges.

New power plants sited on enclosed bays and estuaries also face very restrictive state thermal discharge standards. Water from these sources used for cooling new facilities cannot be heated more than 4°F, virtually ruling out new uses of such waters for once-through cooling.(6) Cooling towers would, therefore, be required for new plants located on these bodies of water, including San Francisco Bay, Los Angeles Harbor and San Diego Bay.

To the extent that the coastal access problems and/or restrictions on thermal discharge dictate the use of cooling towers, municipal waste water would offer potential make-up water supplies at many locations near the coast. Where available and adequately treated, municipal effluent would usually be preferred to sea water for evaporative cooling system operation as an alternative to the

use of fresh water. Should retrofitting of cooling towers be required for any existing coastal plants, waste water sources would have further application.

Conveyance of municipal waste water from coastal communities to cool power plants located some distance inland also appears feasible. As discussed in more detail in Section IV, the Palo Verde Nuclear Generating Station under construction in Arizona will convey Phoenix municipal effluent 37 miles to the plant site. Several important factors should be considered in evaluating a possible use of waste water by a power plant at a site remote from the source. These include costs, pumping energy requirements and environmental effects of constructing and operating the necessary conveyance facilities, all of which will be discussed in the next section.

III. FACTORS WHICH AFFECT FEASIBILITY OF USING WASTE WATER FOR COOLING

The feasibility of using reclaimed municipal waste water for power plant cooling tower make-up has been verified by the operating experience of a number of existing facilities. At least 18 power plants in the United States and several foreign countries are cooled with municipal effluent (see Table 4 in the next section). Several of these applications have been in effect for more than ten years, including the City of Burbank's facility.

Recently, attention has focused on municipal waste water as the primary cooling water source for proposed new power plant projects and as a replacement for the original cooling water source at some existing plants. Three California plants in the latter category are PG&E's Avon and Martinez Plants and the City of Glendale's Plant, all of which have recently been converted to use reclaimed municipal effluent in place of fresh water.

The extent of these applications should not, however, be taken as an indication that the use of municipal waste water for power plant cooling is free of special problems and operational considerations. Many such factors are evident upon reviewing the experiences of the various projects. This section is a general discussion of some of these concerns. Section IV discusses in detail certain cases of effluent reuse for cooling and provides specific examples of the various problem areas.

WASTE WATER QUALITY CHARACTERISTICS

Of primary importance, as with all sources of evaporative cooling system make-up water, is the quality of the waste water supply with respect to parameters of significance to system operation. Effluent quality varies significantly with differences in raw water supply, contributions of storm water, groundwater or

sea water, types of industrial discharges to the sewer system, and treatment processes employed. The most important water quality parameters for cooling system operation that are characteristic of municipal waste water are summarized below:

Total Dissolved Solids (tds) - The tds levels of municipal water supplies in California vary greatly from less than 100 ppm, where the source is a mountain stream, to over 800 ppm where Colorado River water is used. Concentration and addition of impurities as a result of water usage, along with infiltration of more saline waters into the sewage system, can cause tds concentrations in waste water of up to several times that of the source water. This phenomenon is evident in California coastal areas, where tds levels in municipal waste water generally exceed 1,200 ppm TDS, with over 3,000 ppm characteristic of the effluent in certain areas. Generally, municipal treatment processes do not substantially reduce tds. Although municipal waste water tds may approach that of some agricultural waste waters and brackish ground waters, the individual ions contributing to the tds level generally pose less of a scaling problem with municipal effluent.

Nutrients - Nitrogen and phosphorus compounds in domestic sewage pose a major problem for the use of municipal waste water for cooling. These nutrients foster biological growth which can cause system fouling and reduced heat transfer unless controlled. Virtually all power plants use chlorination to control such growth. However, the additional chlorination that may be required to offset the higher biological activity of a waste water supply can be both an economic disadvantage and a problem for disposal of cooling system blowdown.

Suspended Solids - Unlike agricultural drainage water, which is relatively clear, municipal sewage effluent generally has a significant concentration of suspended solids. Deposition and clogging of cooling system passages occurs when an acceptable level is exceeded.

Surfactants - These substances (more properly termed Surface Active Agents) originate in municipal waste water from their use in detergents. They can cause foaming and resultant loss of efficiency and maintenance problems if significant concentrations are present in cooling tower make-up water.

Oil and Grease - Municipal waste water may contain oil and grease, particularly where there is a large industrial contribution. Even small concentrations, if introduced in cooling water, can cause fouling or develop a film which reduces heat transfer.

Avoidance of excessive cooling system operational problems, efficiency losses and maintenance shutdowns due to the effects of one or more of the above waste water constituents may be accomplished in several ways: 1) using a waste water supply that has been extensively treated by the municipal waste water treatment facility; 2) applying additional treatment to the municipal plant's effluent prior to cooling system use; and 3) using a cooling system design and/or mode of operation that minimizes water quality-related problems. The optimal method will usually be some combination of these approaches intended to maintain efficient cooling system operation under design-specified waste water quality conditions. The potential for periodic failures of waste water treatment plant systems and resultant deterioration of effluent quality dictates a need for additional measures which are discussed in an upcoming section.

EXTENT OF MUNICIPAL WASTE WATER TREATMENT

Obviously, the preferable alternative from the utility's standpoint is for the waste water to be as extensively treated as possible. Traditionally, treatment of municipal waste water has been limited to "primary" processes, the use of mechanical methods such as screening and settling (clarification) to accomplish at least a moderate level of suspended solids removal, followed by chlorination for bacteria reduction. This treatment effects little reduction in nutrient levels, and usually also leaves significant effluent concentrations of suspended solids and other waste water parameters. Primary effluent is therefore not of adequate quality to be considered for cooling tower make-up water in most cases.

Unfortunately, about 80 percent of the municipal waste water discharged to the ocean in California presently receives only primary treatment. Included are most of the large volume discharges, in fact all but two of the discharges of 20,000 afy or more (see Table 1). This means that most of the municipal waste water with attractive reclamation potential from a water supply standpoint is not currently of adequate quality to be considered for power plant cooling water.

However, the Federal Water Pollution Control Act contains the goal of secondary treatment for all municipal waste water. Secondary treatment subjects primary effluent to a biological process, the most common being activated sludge or trickling filter, which accomplishes further removal of organic matter and other constituents. Although some additional treatment prior to cooling tower use will usually still be necessary, secondary effluent is generally low enough in suspended solids, oil and grease, surfactants and other parameters to allow its application for cooling.

The original Federal Water Pollution Control Administration secondary treatment deadline of July 1977 has passed, with many municipalities not yet operating secondary plants. Legislation enacted in 1977 allows postponement of the secondary treatment requirement until 1983 for communities whose plans were delayed due to unavailability of grant funds. Another provision of this legislation has particular significance to the potential for waste water reclamation in California. This provision makes it possible for discharges of primary effluent to the ocean through deep outfalls to gain a waiver from the secondary treatment requirement. EPA and SWRCB are now determining which facilities qualify for this waiver. Whether most of the large ocean discharges in the state eventually receive secondary treatment may be largely influenced by the outcome of this determination.

Discharges to San Francisco Bay are apparently excluded from the possibility for a secondary treatment waiver. In fact, Table 1 shows that considerable progress had been made in implementing secondary treatment for waste water discharged to the Bay. Noteworthy examples are the recent additions of secondary treatment by the East Bay Municipal Utilities District and the City of San Jose, making these two the largest dischargers of secondarily treated effluent in the state.

Advanced waste water treatment (called tertiary if it follows secondary in the treatment sequence) is also used by some municipalities. Generally, however, such processes, which are usually designed to remove nutrients, specific organic substances or pathogenic organisms, would be employed only where protection of high quality receiving waters is desired. The South Tahoe Public Utility District Plant is an excellent example. Not only does this facility abate potential pollution of Lake Tahoe, it also provides water via a 27 mile long pipeline to support a smaller recreational lake.

COST OF EFFLUENT PURCHASE

A wide range of prices have been paid to date by utilities for treated municipal effluent. The purchase price can usually be expected to reflect the extent of municipal treatment processes employed and the resultant effluent quality. Although charges for waste water are usually less than for fresh water supplies, it appears ulikely that secondary treated effluent would ever be available free of charge.

Reported costs paid for municipal effluent by power plants range from $8 to $104 per acre foot with an average of about $35/af (1974).(7) The latter (average) cost would represent about 0.03-0.08 mills/kWh and the higher cost about 0.09-0.23 mills/kWh for a range of steam-electric power plants.*

ADDITIONAL TREATMENT NECESSARY FOR POWER PLANT USE

Regardless of the characteristics of the waste water source, some special treatment in addition to that necessary for fresh water will virtually always be required to accommodate the use of municipal waste water in power plant cooling systems. However, the type of extra treatment, and its cost, will vary considerably with waste waters of different qualities.

Depending on the specific quality characteristics of the secondary effluent used, one or a combination of several further treatment methods will usually be necessary. These include softening with lime-soda ash or ion exchange treatment, filtration for suspended solids removal, denitrification (ammonia removal), chemical precipitation (using lime, aluminum, iron or other precipitants) for removal of phosphate and other specific ions, demineralization with

*The range is based on total make-up water requirements of from 0.3 gallons per kWh of generation (e.g. combined cycle plants) to 0.75 gallons per kWh of generation (e.g. nuclear plants).

either to the make-up flow or to a "sidestream" of the circulating water flow. As with virtually all cooling water treatment programs, various types of chemical additions will also be required, including chlorination for controlling biological growth, acid for pH control, corrosion inhibitors and perhaps an anti-foaming compound.

The treatment program selected for municipal waste water as cooling tower make-up will usually include a chemical precipitation process, often augmented with denitrification and filtration. Typical capital costs for such treatment would be in the range of $10 million (1978) for a system capable of treating 10 million gallons per day (MGD), or about 11,000 afy. With the addition of costs of chemicals and other operation and maintenance expenses, estimates of total treatment costs range from $200 to almost $500 per acre-foot of water treated.(8,9) This treatment cost range applied to a range of power plant water requirements results in an incremental addition to total generating costs of between 0.2 and 1.1 mills per kilowatt hour.

Although primary-treated effluent is generally not considered to be of adequate quality for cooling system use, a utility could conceivably secure a source of municipal primary effluent and apply the equivalent of secondary treatment, along with whatever additional treatment would be needed to produce a make-up water supply of adequate quality. While nothing less than secondary effluent is known to have been considered to date for cooling use, the increasing difficulty of obtaining power plant water supplies could result in primary effluent being considered in some cases. However, the capital cost of activated sludge treatment of primary effluent would be about $13 million for a 10 MGD facility.(10) Operation and maintenance costs would be additional. Therefore, a secondary-treated waste water source, if not an absolute prerequisite, certainly repre-

sents a distinct economic advantage over a primary-treated source for application to power plant cooling.

In rare cases, a secondary plant effluent may be of satisfactory quality for cooling system use without the employment of further treatment processes other than chemical addition. The City of Burbank case, discussed more fully in the next section, is an example. In another application, by the City of Croyden, England (one of the oldest users of municipal effluent for cooling), the cooling tower itself acts as a tertiary treatment step for nutrient reduction.(11)

SPECIAL COOLING SYSTEM DESIGN AND OPERATING MODES

To some extent, cooling system design and operation can be tailored to help reduce problems associated with the use of low-quality water sources, such as municipal waste water. The options in this category include use of corrosion-resistant materials, inclusion of special maintenance features and limiting the number of cycles of concentration.

Most applications to date of municipal waste water for power plant cooling have involved previously operated cooling towers, with the waste water source substituted for the original fresh water source. Thus, the opportunity to incorporate special features for waste water use into the initial tower design has not generally existed. The Palo Verde Project is a notable exception. A pre-construction pilot project (see further discussion in the next section) tested the cooling water treatment processes selected, and also evaluated the compatibility of various materials with the treated waste water.(12) Based on this testing, special materials features for the actual plant circulating cooling water system were selected, including:

- Concrete, rather than wood, cooling tower construction, since wood was observed to deteriorate rapidly, apparently due to the residual ammonia concentration in the waste water.
- Avoidance of copper-bearing materials in the entire circulating water system due to observed corrosion rates of these materials.
- The use of titanium alloy condenser tubing.
- The use of an aluminum-bronze alloy and special corrosion-resistant coatings for various system components.

The experience of this project should provide a valuable reference for materials selection for future cooling towers designed for waste water use.

Special provisions to clean heat exchange surfaces and other cooling system components can also help reduce problems associated with the use of waste water. One type of cleaning system allows condenser tube cleaning during the course of normal operation through the use of balls of sponge rubber or similar material, of slightly larger size than the internal tube diameter. When passed through the tubes via the circulating water flow, the balls abrasively remove scale accumulation such that their periodic use can maintain effectiveness of heat transfer surfaces. Other methods of heat exchanger maintenance such as chemical cleaning and manual brushing require the system to be in a shutdown condition. Reliance on these methods to accommodate the use of a low-quality cooling water supply will therefore require a higher than normal rate of scheduled plant outages for maintenance.

The cost of special cooling system design and construction features for reducing problems associated with waste water use appears nominal, in light of the

benefits of avoiding increasing outages for maintenance and/or replacement of components. The additional cost of such features will likely be 10-25 percent of the basic cooling system cost.(13) Thus, a $40/kW capital cost of a conventional system might become $44 to $50/kW if designed to accept a waste water source.

Of primary consideration in assessing the use of municipal waste water in cooling towers are the cycles of concentration* to be employed. If a sufficient volume of waste water supply is available and blowdown disposal can be readily accomplished (e.g., by return to the remaining waste water treatment plant effluent), operating at low cycles of concentration can be used to minimize operational problems with less extensive treatment. To date, most applications of municipal waste water for cooling have involved low cycles of concentration (i.e., from 2 to 4 cycles). Where waste water supply and blowdown discharge restrictions are not limiting, an economic evaluation might be desirable for a planned use of waste water to allow optimization of cycles of concentration with respect to treatment cost. This would involve comparing the cost of applying minimal treatment to a larger volume of make-up water (and operating at low cycles) with more extensive treatment of a smaller volume of water (and operating at higher cycles). The Palo Verde Project has chosen the latter concept and plans to operate at 15 cycles of cooling water concentration.

CONVEYANCE COSTS

The capital cost of conveyance pipelines with pumping stations and related facilities ranges from about $400,000/mile for a 30-inch line serving a 1,000 MW Combined Cycle Plant (or a 400 MW fossil steam plant) to over $1.5 million/mile

*Cycles of concentration refers to the number of times impurities present in the initial makeup water are concentrated by cooling tower evaporation.

for a 60-inch line for a 2-unit (2400 MW) nuclear plant.* Based on this, it can be seen that every 10 miles of conveyance distance adds roughly $4-6 per kW to the capital cost of such plants. The total capital and O & M cost (exclusive of energy cost) of a 40 mile conveyance pipeline would contribute an estimated 0.4-0.7 mills per kilowatt hour to the plants' generation costs.**

Pumping energy requirements are another important variable. Every acre-foot of water pumped requires about 1.5 kWh of electric energy per foot of lift (vertical distance plus pipe friction losses equal to about 8 feet per mile).(15) Therefore, each 100 vertical feet or each 12.5 linear miles of cooling tower make-up water pumping for a conventional steam-electric plant requires roughly 0.03-0.04 percent of the plant's electric generation.***

Pipeline routes may also partially determine the feasibility of long distance conveyance. Crossing steep terrain will not only increase pumping power requirements but will also add to pipeline construction costs. Routes which run under water or through urban areas could also be more expensive due to added construction and right-of-way acquisition costs. Environmental concerns may sometimes rule out corridors that are otherwise desirable. An extensive study of alternative pipeline routes was conducted for the Palo Verde Nuclear Project, resulting in selection of a preferred route based on a number of environmental and socio-economic criteria.(16)

None of these factors necessarily rule out consideration of municipal waste water sources for cooling power plants at distant sites. However, careful

*Based on pipeline cost data from Ref. 14 (1976 dollars).

**Assumes a 16 percent fixed charge rate, 80 percent plant capacity factor, and O & M cost equal to 15 percent of the annual capital cost.

***Such plants typically produce 400,000-600,000 kWh of electricity per AF of make-up water used.

weighing of economic, energy and environmental factors may, in many cases, favor the use of another water source closer to the power plant site and reuse of waste water effluent for other purposes (e.g., landscape irrigation) nearer the treatment plant. The objective of locating a power plant near a waste water source may even be in general conflict with certain other environmental siting criteria (e.g., air quality).

In this regard, it may be prudent to consider possible arrangements whereby utilities would participate in the financing of projects which reclaim municipal waste water in the coastal regions in exchange for a fresh water supply for a distant power plant project. The extensive and interconnected network of water delivery systems in the state could facilitate applications of this concept, possibly resulting in net savings of pumping energy.

WASTE WATER SUPPLY RELIABILITY

While reliability of cooling water supply is an important consideration for all power plant projects, the selection of a municipal waste water source involves additional unique factors. Normal fluctuations in sewage flow on a daily, weekly and seasonal basis pose a potential problem for maintaining a continuously adequate flow of treated effluent for cooling tower make-up, particularly if the waste water source volume is only marginally adequate to begin with. This problem can be minimized by securing a waste water source considerably in excess of the power plant's projected make-up water need and/or by providing storage of treated waste water. A careful evaluation of historical flow records of a waste water treatment plant should be used to assess supply adequacy if the annual effluent flow is not greatly in excess (i.e., 1.5 times or more) of the power plant's cooling water need. For example, some of the treatment plants

listed in Table I as discharging about 5,000 afy might only represent a reliable source of cooling water for a power plant with a 3,000 afy cooling water requirement upon examination of their flow patterns.

Storage of a certain amount of water at the power plant can be used both to offset variations in sewage flow and to provide a contingency supply in case of another major problem area--treatment plant shutdowns and upsets. The operating histories of waste water treatment plants contain periodic instances of employee strikes, equipment malfunctions and treatment process disruptions caused by nonroutine introductions of industrial chemicals and other substances into the sewer system. The fact that the treatment plant reliability is high (often 98 percent of more) compared with the power plant's projected capacity factor (usually 80 percent or less) is incidental, since there is no assurance that treatment plant outages will coincide with power plant down time. Even at 98 percent treatment plant reliability, less than adequate treatment can be expected for the equivalent of 7 full days per year.

Maximum insurance against forced power plant shutdown due to an insufficient supply of adequately treated waste water requires that a back-up water supply source be available. For most plants using waste water, this has simply meant retaining the connection with the original water source (usually fresh surface or groundwater) which the waste water source replaced. In lieu of such a back-up supply, water storage becomes critical to power plant reliability. The Palo Verde Project will operate without an alternate water source but, instead, will maintain a storage reservoir containing an eight-day water supply. This reservoir, for the three 1,270 MW nuclear units, will hold 635 million gallons and occupy 80 acres.

ENVIRONMENTAL IMPLICATIONS

The use of municipal waste water as power plant cooling tower make-up water has both positive and negative environmental implications. Using waste water effluent for cooling can have a water quality benefit to the normal receiving water by reducing the volume of effluent discharged. However, in the case of adequately treated effluent that is discharged to inland waters, the reduction of flow resulting from such a diversion may be considered detrimental (see Palo Verde Project discussion in Section IV).

Another aspect of municipal waste water use for cooling tower make-up commonly considered an environmental benefit and, in fact, providing the impetus for using this source, is avoidance of the use of a higher quality water source. Where the fresh water which would otherwise be used is left for in-stream uses (e.g., fish and wildlife habitat enhancement), the use of waste water that is not being returned to a usable body of water would represent a real environmental benefit. However, given the nature of California's water development and allocation system, much of the fresh water that would be applied to power plant cooling would ultimately be applied to some out-of-stream uses (e.g., agricultural irrigation). This, plus the fact that the amount of degraded-quality waste water which results from these other uses is usually proportionately greater than from power plant cooling use, tend to minimize the true environmental benefit attributable to substituting lower quality sources for fresh water for power plant cooling. Of course, a general enviromental benefit of all waste water reclamation projects, as well as water conservation programs, is reduction of the need for new water projects with their associated impacts on the natural environment.

Realistically, the movement toward waste water and other alternative sources of power plant cooling water should be viewed primarily as a response to institutional policies which seek to protect fresh water for other uses, primarily agricultural irrigation. However, the water supply benefit of using municipal waste water for cooling should be carefully weighed against the adverse environmental and public health impact potential associated with such an application. Two major categories of potential impacts require attention when considering the use of municipal effluent as cooling tower make-up water: 1) impacts resulting from disposal of cooling system blowdown containing the concentrated constituents of the waste water source plus additive substances; and 2) impacts associated with aerosol emissions from the cooling tower, also containing constituents of the waste water, with particular respect to pathogenic organisms.

If the cooling water source is relatively high quality fresh water, cooling tower blowdown can usually be discharged to surface water, even when up to 10 cycles of concentration are practiced. Several existing California power plants use fresh water discharge blowdown of high enough quality to permit its use for crop irrigation. The use of municipal waste water as the cooling water source will usually result in blowdown that is unacceptable for discharge to any body of water, due to the presence of the concentrated residual waste water constituents and additives used in the cooling water treatment program. Disposal options include treatment to a level that will allow discharge, in-plant recycling, evaporation basins, discharge to the municipal sanitary sewer system or recombination with the remaining effluent from the municipal system.

The latter method, where possible, has the most advantage from the power plant's standpoint. However, this could cause the concentrations of pollutants in the

municipal discharge to exceed acceptable levels unless the blowdown stream is small compared to the effluent discharge. The State Water Resources Control Board staff has indicated that such exceedences may, in some cases, be allowed, to further the objective of waste water reclamation.(17) Discharge to the sanitary sewer may also be a problem due to the increased hydraulic load on the treatment plant as well as possible effects on sewer system and on treatment plant operation resulting from blowdown constituents.(18) Again, the acceptability of this option will generally depend on the relative volume of blowdown versus waste water treatment system capacity. Use of municipal waste water at remote power plant sites would impose a further constraint on either of these methods of blowdown disposal, since a separate discharge return line would be necessary.

Coal-fired power plants have the advantage of being able to dispose of blowdown while reducing in-plant water use through a concept known as "cascading" water use. This involves the use of waste streams from some processes as make-up water for other systems which can tolerate low-quality water. In a coal-burning plant, cooling tower blowdown can be used as make-up for the ash handling and flue gas desulfurization systems. The water quality requirements of these systems, while relatively lenient, may be a cause for some concern when the original source of the cascaded make-up water is municipal waste water. The use of cooling tower blowdown in these systems may necessitate operating the cooling system at low cycles of concentration in order to avoid scaling, corrosion or fouling problems due to certain waste water constituents.

In lieu of other options, blowdown disposal will usually come down to a choice between treatment technologies for improving the quality (and/or reducing the quantity) of the blowdown stream and evaporation basin disposal. To date,

expedience and economics have favored the latter method, especially in arid areas where evaporation rates are high and where large expanses of land can be obtained at a reasonable cost. However, this situation could change due to several factors: 1) strict requirements for groundwater protection requiring the use of expensive liners for evaporation basins; 2) scarcity and expense of the large land areas needed for these basins and environmental objection to such use of the land; 3) advances in technologies for reducing or treating the blowdown; and, 4) the increasing difficulty and expense of obtaining and treating plant water supplies along with the advancement of water conservation eforts. Therefore, increasing consideration of technologies to minimize evaporation basin disposal of cooling tower blowdown and other plant waste waters is expected for new power plant projects, whatever the source(s) of plant water supply.

Regardless of how blowdown disposal is accomplished, complications are almost certain to result when municipal waste water is the cooling water source. Both the increased quantity and the lower quality increase the difficulty of disposing of the blowdown in an environmentally acceptable manner. Increased quantities of residues, such as lime sludge, from water treatment processes will also require disposal.

Despite the substantial experience with the use of municipal effluent in cooling towers, relatively few studies have been conducted which characterize or assess impacts of airborne emissions from towers which use waste water. One researcher who has studied the presence of microorganisms in the exhaust of cooling towers using municipal effluent, reports that the potential health hazard from biological aerosols is closely related to the effectiveness of the treatment processes employed by both the waste water treatment facility and the

power plant.(19) Table 2 lists the various pathogenic microorganisms that may be found in domestic sewage. Should the treatment processes at any time fail to accomplish a high level of disinfection, the number of microbes exiting the tower, possibly including disease-producing bacteria, viruses or other organisms, may become significant.

The extent of variation in such emissions with different waste water conditions is illustrated by measurements conducted by this researcher on two different cooling towers using municipal waste water. In one case, a tower using inadequately treated make-up water was found to be expelling microbe-bearing particles at a tremendous rate, calculated at 0.8 billion per minute for one cell of the tower. Another tower, tested during the use of two different methods of make-up water disinfection, had much lower levels of microbial emission.

The latter tower did exhibit significantly different levels of emitted microbes with the two methods of disinfection. With conventional chlorination, using gaseous chlorine, water in the cooling tower basin contained 175,000 bacteria per milliliter and a cubic meter of air exiting the tower contained 2,900 bacteria-bearing particles. After the use of a newer disinfectant, chlorine dioxide, was adopted, the number of bacteria in the basin water dropped to 180 per ml and only 50 bacteria-bearing particles per cubic meter of exhaust air were observed. The latter method of disinfection, or some other method such as ozone treatment, therefore appears preferable when municipal waste water is used for cooling tower make-up.

In addition, selection of processes for further treatment of the waste water supply by the power plant should consider methods which not only improve chemical quality, but reduce microbial concentrations as well. For example,

treatment of secondary effluent using substantial quantities of hydrated lime with a clarification process (high-lime treatment) enhances bacteria and virus reduction while also accomplishing reductions in suspended solids, hardness, silica and other potential problem parameters.

Other provisions that will help minimize the public health hazard from cooling towers which use waste water include: 1) selecting as waste water sources only treatment plants with a history of stable operation and high quality effluent production; 2) maintaining direct communication between the waste water treatment facility and the power plant for notification in case of abnormal effluent conditions; 3) providing an alternate cooling water supply to be used when quality of the waste water supply falls below acceptable levels; 4) employing the most effective cooling tower drift reduction designs and 5) routinely monitoring cooling tower water quality for the presence of microorganisms. Of course, if power plants can be sited away from populated areas and still convey municipal waste water for cooling, the potential health risk would be further lessened.

While less of a consideration than microbial constituents, certain chemical impurities may be present in municipal waste water in sufficient concentrations to be of concern from the standpoint of air emissions. The California Air Resources Board has recently become interested in particulate emissions from cooling towers which use waste water and other low-quality sources of make-up water. If the total solids (dissolved plus suspended solids) concentration of cooling tower drift is considered as particulate, cooling towers using municipal waste water could emit from 2 lbs./hr. to over 30 lbs./hr. of particulate per 100 MW of plant capacity, depending on source water quality, cycles of concentration, and drift elimination efficiency. The actual environmental significance

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of such emissions will likely depend on the nature of the specific contributing substances. For example, the presence of heavy metals due to industrial discharges to the sewer system could be a cause for concern.

TABLE 2

PATHOGENIC MICROORGANISMS POTENTIALLY PRESENT IN SEWAGE EFFLUENT

Microorganism	Disease Caused
Bacteria:	
Salmonella	typhoid, paratyphoid and gastroenteritis
Yersinia	gastroenteritis
Shigella	bacillary dysentery
Mycobacteria	tuberculosis
Staphlococci	pneumonia, bronchitis, boils, etc.
Streptococci	pneumonia, septicemia
Leptospira	leptospirosis (Weils Disease)
Viruses:	
Poliovirus	poliomyelitis
Hepatitis Type A	infectious hepatitis
Echovirus	meningitis, respiratory disease, diarrhea and fever
Coxsackie A	herpangia, respiratory disease, meningitis and fever
Coxsackie B	myocarditis, congenital heart anomalies, rash, fever, meningitis, respiratory disease
Reovirus	gastroenteritis, respiratory disease
Adenovirus	respiratory disease, eye infections
Protozoa:	
Endomoeba histolytica	amoebic dysentery, liver abscesses
Giardia lamblia	diarrhea and gastroenteritis

IV. APPLICATIONS BY ELECTRIC UTILITIES

Table 3 lists known applications of municipal waste water for power plant cooling in the United States and several foreign countries totalling over 5,000 MW of existing capacity. Other cases may exist that have not been documented. In addition to power plant cooling, there are many examples of municipal waste water used as cooling tower make-up water in the petroleum refining and chemical industries. Although such applications are not within the scope of this study, they constitute extensive operating experience with the use of such waste water for cooling and provide further sources of reference information on the subject.

The following sections describe the actual experience of several utilities in California and other western states which have adopted the use of municipal effluent for cooling tower make-up. A major project currently under construction is also discussed. Together, these examples comprise the most notable and best documented experience with this practice and illustrate its technical feasibility as well as the range of technical problems which it presents.

SOUTHWESTERN PUBLIC SERVICE COMPANY

This company has more extensive operating experience with waste water for cooling than any other United States utility.(20,21,22) It has cooled one power plant, the Nichols Station at Amarillo, Texas, with reclaimed effluent since 1961 and has since applied waste water for cooling at two other plants, the Jones Station at Lubbock, Texas and the Harrington Station, also at Amarillo. The total existing capacity of the three plants is now 1,300 MW and their cumulative cooling water make-up requirement of about 17,000 afy is supplied almost entirely with additionally treated secondary effluent from the cities of Amarillo and Lubbock. At certain times of the year, the waste water flows are insufficient and are supplemented with well water.

TABLE 3

APPLICATIONS OF MUNICIPAL WASTE WATER USE FOR POWER PLANT COOLING

UTILITY/PLANT/LOCATION	CAPACITY (MW)	YEAR USE OF WASTEWATER INITIATED
ESTABLISHED U.S. APPLICATIONS		
City of Burbank, California Olive and Magnolia Plants	154	1967
Nevada Power Company Clark and Sunrise Stations Las Vegas, Nevada	290	1961
Los Alamos National Laboratory New Mexico	20	1951
Southwestern Public Service Company Nichols and Harrington Stations Amarillo, Texas	820	1961
Jones Station, Lubbock, Texas	500	
Lansdale Municipal Power Plant Lansdale, Pennsylvania	33	—
Public Service Company of Oklahoma Comanche Plant (cooling lake)	120	1975
City of Richmond, Indiana Whitewater Plant (periodic use)	90	1972
City of Denton, Texas (abandoned)	190	1968
OUTSIDE THE U.S.		
City of Croyden, England	1,370	1950
South Rhodesia	120	1960
Federal Electricity Committee of Mexico, Monterey Mexico	—	1968
South Africa (6 plants)	1,230	—
RECENT AND PLANNED APPLICATIONS		
City of Glendale, California Grayson Plant	212	1978
PG&E, Avon and Martinez Plants Contra Costa County, California	80	1979
Arizona Public Service Company Palo Verde Nuclear Project	3,900	1982 (scheduled)

Early evaluation of the secondary effluent quality resulted in the selection of a lime softening treatment process to reduce potentially scale-forming concentrations of phosphates, magnesium and silica. The lime treatment also reduces BOD and this, along with heavy chlorination, is used to control biological growth. Table 4 provides a water quality comparison of the city's fresh water supply, the secondary municipal effluent, the treated cooling water supply and the cooling tower blowdown.

Problems experienced in initial operations with waste water revealed that the treatment program alone would be inadequate to permit cooling system operation at the desired five cycles of concentration. An Amertap Cleaning System (which uses the sponge rubber ball concept) was, therefore, retrofitted to control condenser tube fouling and scale formation. An 85 to 90 percent cleanliness factor for the heat exchange surfaces is maintained by this method. A further step to accommodate the use of waste water was the installation of stainless steel condenser tubing in the newer generating units, rather than the admiralty brass used in the older units. This material has shown excellent corrosion resistance. The use of phenolic and epoxy coatings and magnesium electrodes provide corrosion protection for other metallic components of the circulating water system. Foaming has been observed, including some emitted as lumps from the cooling tower stacks, but has apparently caused no operational problems.

In addition to the use of compacted earthen evaporation basins, the company is experimenting with saline irrigation as a method of blowdown disposal. Blowdown has been used directly and blended with secondary effluent for irrigating various salt tolerant crops. The degree of difficulty involved with this effort was increased when Amarillo switched its water supply from groundwater to a surface water source, resulting in a substantial increase in tds.

TABLE 4

TYPICAL WATER ANALYSES OF NICHOLS STATION OF SOUTHWESTERN PUBLIC SERVICE COMPANY*

As $CaCO_3$	Amarillo Fresh Water	Sewage Effluent	Cooling Tower Makeup	Cooling Water
Ca	170	185	180	940
Mg	120	150	42	210
Na	484	584	584	2,994
K	7	20	20	100
NH_3	0	73	73	8
HCO_3	170	220	40	32
CO_3	0	0	60	0
SO_4	270	293	350	1,800
Cl	341	443	443	2,215
NO_3	0	5	4	145
PO_4	0	51	2	10
SiO_2	9	28	10	50
pH	8.1	7.3	9.2	7.0
BOD	0	15	2	6

*Analysis results corrected for calculated cation and anion balance.

CITY OF BURBANK, CALIFORNIA

The City of Burbank Public Service Department has, since 1967, successfully used effluent from the city's own secondary treatment plant to supply most of the make-up water needs of its two steam-electric plants.(23,24,25) About 1,800 afy of reclaimed waste water is supplied for cooling tower use, with the original city fresh water supply serving only a stand-by function during periods of inadequate effluent quality.

A somewhat unique feature of the Burbank example is utilization of the waste water treatment plant effluent directly as cooling tower make-up, without additional treatment processes. A carefully controlled internal cooling system water treatment program and low cycles of concentration have proved adequate to maintain efficient system operation without extraordinary maintenance. The

primary component of the treatment program is utilization of the high orthophosphate concentration in the waste water to act as a corrosion inhibitor. This necessitates close control of pH (with sulphuric acid addition) and the use of phosphonate and polyacrylate compounds to minimize phosphate scale formation. The use of chlorine dioxide as a disinfectant has provided excellent control of microorganisms.

The ability to maintain low cycles of concentration is important to satisfactory operation without additional treatment. Initial operation at four cycles resulted in a decrease in condenser heat transfer efficiency, with a cleanliness factor of 68 percent (compared with a normal 70-80 percent factor) recorded after two years in this mode. This and other problems, including foaming, have been solved and a limit of 2.5 cycles is now maintained. This is possible since an excess of municipal effluent is available and blowdown can be discharged to the Los Angeles River channel system with the remaining effluent. Table 5 shows the typical water qualities at the various points in Burbank's process.

Converting to waste water has had considerable advantage for Burbank. The city water supply previously used was causing problems with condenser tube corrosion and cooling tower wood deterioration that has actually improved with the use of waste water. Foresight in planning the waste water treatment facility resulted in a construction feature that allows delivery of effluent to the power plant by gravity flow.

NEVADA POWER COMPANY

Nevada Power is another long-time user of municipal waste water for cooling, at its 200 MW Clark Station since 1961 and its 90 MW Sunrise Station since 1964.(26,27) The entire cooling tower make-up water supply for the plants, both

in the Las Vegas area, is secondary effluent from the City of Las Vegas and Clark County Waste Water Treatment Plants. Both power plants are located within 1.5 miles of the waste water treatment plants.

TABLE 5

TYPICAL WATER ANALYSES - CITY OF BURBANK POWER PLANTS

Results in ppm	5/3/73 City Composite Well & MWD	4/15/73 Reclaimed Makeup to Cooling Towers	4/15/73 Cooling Tower	4/15/73 Blended Discharge
Total Hardness ($CaCO_3$)	194.0	182.0	467.0	230.0
Calcium	52.0	47.1	118.0	61.4
Magnesium	15.5	15.7	41.8	18.6
Sodium	36.6	89.0	288.0	147.0
Total iron	0.05	0.0	0.14	0.14
pH	7.75	7.15	6.55	7.20
Bicarbonate Alkalinity ($CaCO_3$)	147.0	172.0	22.8	140.0
Chlorides	38.8	89.7	240.0	121.0
Fluorides	0.74	1.1	2.2	1.18
Sulfates	105.0	168.0	700.0	297.0
Phosphates	0.0	36.0	74.0	39.0
Nitrate	5.2	26.0	159.0	47.0
Total Solids	386.0	560.0	1,656.0	772.0
TDS	386.0	555.0	1,649.0	763.0
Total Suspended Solids	0.0	5.0	7.0	9.0
Silica	15.1	19.4	48.0	24.8
Conductivity @ 25°C	505.0	795.0	1,710.0	1,000.0
Aluminum	0.04	0.02	0.22	0.04
Manganese	0.0	0.01	0.04	0.02

Initially, waste water at Clark Station was used with only chemical addition. Phosphate concentrations in the effluent made additional treatment necessary however, and lime softening in a reactor-clarifier was the method selected. This process reduces phosphate from an initial 14-35 ppm to less than 1 ppm, allowing cooling system operation at up to 5 cycles of concentration, at which point calcium concentrations become the limiting factor. Only slight cooling

system fouling and scaling has been observed and has been controlled with normal maintenance programs. Foaming, previously a problem, has not been observed since the on-site treatment was initiated.

Storage ponds, holding approximately a two-day supply of effluent at Clark Station and a four-day supply at Sunrise Station have been provided for standby use and also to help stabilize fluctuations in effluent quality. The capability of supplying Sunrise Station from either the Las Vegas or the Clark County treatment plants provides adequate reliability of supply for this plant. The Clark Station maintains a connection with the Las Vegas municipal water system for a back-up supply.

The successful use of waste water at the Clark and Sunrise Stations and the scarcity of water resources in Nevada have led to Nevada Power Company's intent t also use waste water for cooling its proposed Harry Allen Station. Effluent from the Clark County Advanced Waste Water Treatment Plant will be used at this coal-fired plant, scheduled for operation in 1985. A 24 mile conveyance pipeline is planned to carry effluent from the treatment plant to the power plant and also to an agricultural irrigation project.

PACIFIC GAS AND ELECTRIC COMPANY

PG&E's two 40 MW facilities at Avon and Martinez are among a group of industries which were selected for conversion to waste water as part of the Contra Costa County Water District's (CCCWD) Reclaimed Water Project.(28,29) This project was undertaken by CCCWD in order to avoid the need for an expanded fresh water supply system.

Initially, 15 million gallons per day (about 17,000 afy) of effluent from the Central Contra Costa Sanitary District's new secondary facility is being pur-

chased by CCCWD, given additional treatment by the District and supplied for cooling use by five industrial customers, including PG&E. The project is designed for an ultimate capacity of twice this amount.

Although the substitution of waste water for fresh water as cooling tower make-up was not voluntary on the part of the users, CCCWD worked closely with the industries to insure compatibility of the delivered effluent with their systems. Of particular significance was the District's early decision that any additional costs incurred in using waste water should be borne by all the district's water users rather than inflicted only on the selected user industries. Thus, the ion-exchange pretreatment facility will be funded and operated by CCCWD, with the water delivered to the industries intended to be of a quality that will allow its use at no additional cost over the previous fresh water supply. Substantial increases in both the District's water rates and its ad valorum tax rate will result from the over $5 million project. However, costs of other options evaluated for increasing CCCWD's water supply capabilty were much higher.

CITY OF GLENDALE, CALIFORNIA

Following the City of Burbank's example, the City of Glendale has developed a project to reuse of a portion of its waste water to serve the cooling water needs of its 200 MW Grayson Power Plant.(30,31) Following initial testing of the effluent as cooling tower make-up, full conversion to operation with waste water was accomplished in 1978. The use of waste water replaces groundwater previously supplied from the city's wells. The latter source now provides a back-up supply.

A most significant factor in this project, and one which gives cause for optimism for the waste water-for-cooling concept, was the securing of state/

federal construction grant funds for a major portion of the $3 million capital cost of the additional treatment and conveyance facilities required.

PALO VERDE NUCLEAR PROJECT

A consortium of five western utilities led by the Arizona Public Service Company (APS), and including the Southern California Edison Company, is engaged in the construction of the Arizona Nuclear Power Project.(12,16,32,33) This project, which is planned to ultimately consist of Palo Verde Nuclear Generating Stations 1, 2 and 3, totaling 3,900 MW of capacity will utilize municipal waste water from the Phoenix metropolitan area for its entire cooling tower make-up requirement. Not only will this be the largest power plant, and the first nuclear plant using reclaimed waste water (up to 75,000 afy), but it will also be significant in that the power plant site is remote from the waste water treatment plant. A conveyance pipeline costing roughly $40 million will carry the secondary treated effluent about 37 miles to the power plant, the longest water conveyance distance known to have been selected to date for a power plant.

Another notable feature of the Palo Verde Project is the intention of operating the cooling system at high cycles of concentration (15), the highest number of cycles reported to have been considered for the use of municipal waste water. To confirm the feasibility of this mode of operation, and to demonstrate the effectiveness of the pretreatment processes selected, APS carried out a pilot project which treated a 40 gallons per minute (gpm) waste water stream for make-up to a 100 gpm cooling tower and circulating water system. This testing indicated that the treatment, which includes trickling filters for ammonia reduction, a two-stage lime softening process and filtration through coal and sand media, allows satisfactory cooling system operation with up to 20 cycles of concentration.

The above treatment sequence represents the most extensive treatment yet applied to municipal waste water for use as a cooling tower make-up. Capital cost of the treatment system has been estimated at about $50 million, with chemical costs amounting to over $1 million per year (1974). Special cooling system materials selection (see discussion in Section II) will be a further cost addition due to the use of waste water.

The Palo Verde Project illustrates the mixed benefits of reclaiming inland waste water. Although use of waste water by the plant avoids a new demand for fresh water resources, considerable environmental concern has been voiced over the arrangement. The waste water effluent is presently discharged to the Salt and Gila Rivers, helping to support a greenbelt and wildlife conservation area which the Federal Bureau of Land Management and the Arizona Game and Fish Department co-manage on the river system. Some degradation of wildlife habitat, riparian vegetation and fisheries is expected to occur as a result of the diversion of the waste water for cooling.

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